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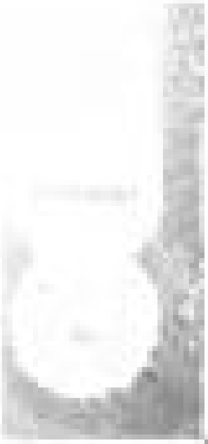
ABSTRACT

This document gives definitions and symbols for the basic units of measure, for derived units, and for supplementary units. Decimal multiples and sub-multiples of units and units outside the International System also are discussed. Appendix I reproduces the decisions made on units and on the International System by two committees (the General Conference of Weights and Measures and the International Committee of Weights and Measures) since 1889; Appendix II outlines methods which metrological laboratories can use to derive the units and to calibrate standards. (DT)



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The International System of Units (SI)

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The International System of Units (SI)

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(Translation approved by the International Bureau of Weights and Measures of its publication "Le Système International d'Unités")

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The International System of Units

Foreword

This document, now published independently by the National Bureau of Standards, USA, and Her Majesty's Stationery Office, UK, is a translation of the French "*Le Système International d'Unités*" published by the International Bureau of Weights and Measures.* It was prepared jointly by the National Physical Laboratory, UK, and the National Bureau of Standards, USA. The International Bureau of Weights and Measures has compared this translation with the French text and finds that it agrees with the intention and the letter of the original. The only difference between the English and American versions lies in the spelling of "metre", "litre", "deca", "black body", and "ideas" in the UK [illegible] and "meter", "liter", "deka", "blackbody", and "idea" in the USA publication. The International Bureau hopes that wide dissemination of this approved translation will promote knowledge and understanding of the International System of Units, encourage its use in all realms of science, industry, and commerce, and secure uniformity of nomenclature throughout the English-speaking world.

J. Terrien

Director

BIPM

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* "*Le Système International d'Unités*," 1970, OFFILIB, 48 rue Gay-Lussac, F 75 Paris 5. [illegible]

Translations have also been published in several other languages, [illegible]

Preface

The International Bureau of Weights and Measures (BIPM), in response to frequent requests, publishes this document containing Resolutions and Recommendations of the General Conference of Weights and Measures (CGPM) on the International System of Units. Explanations have been added as well as relevant extracts from the Recommendations of the International Organization for Standardization (ISO) for the practical use of the System.

The Consultative Committee for Units (CCU) of the International Committee of Weights and Measures (CIPM) helped to draft the document and has approved the final text.

Appendix I reproduces in chronological order the decisions (Resolutions, Recommendations, Declarations, etc.) promulgated since 1889 by the CGPM and the CIPM on units of measurement and on the International System of Units.

Appendix II outlines the measurements, consistent with the theoretical definitions given here, which metrological laboratories can make to realize the units and to calibrate precision material standards.

This 2d Edition is brought up to date with the decisions of the 14th General Conference of Weights and Measures (1971) and takes account of several amendments proposed by the Consultative Committee for Units.

January 1973.

J. TERRIEN
Director, BIPM

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President, CCU

The International System of Units

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I. INTRODUCTION

I.1 Historical note

In 1948 the 9th CGPM[1], by its Resolution 6, instructed the CIPM[1]: "to study the establishment of a complete set of rules for units of measurement"; "to find out for this purpose, by official inquiry, the opinion prevailing in scientific, technical, and educational circles in all countries" and "to make recommendations on the establishment of a *practical system of units of measurement* suitable for adoption by all signatories to the Metre Convention."

The same General Conference also laid down, by its Resolution 7, general principles for unit symbols (see II.1.3, page 8) and also gave a list of units with special names.

The 10th CGPM (1954), by its Resolution 6, and the 14th CGPM (1971) by its Resolution 3, adopted as base units of this "practical system of units", the units of the following seven quantities: length, mass, time, electric current, thermodynamic temperature, amount of substance, and luminous intensity (see II.1, page 3).

The 11th CGPM (1960), by its Resolution 12, adopted the name *International System of Units*, with the international abbreviation *SI*, for this practical system of units of measurement and laid down rules for the prefixes (see III.1, page 20), the derived and supplementary units (see II.2.2, page 10 and II.3, page 11) and other matters, thus establishing a comprehensive specification for units of measurement.

In the present document the expressions "SI units", "SI prefixes", "supplementary units" are used in accordance with Recommendation 1 (1969) of the CIPM.

[1] For the meaning of these abbreviations, see the preface.

I.2 The three classes of SI units

SI units are divided into three classes:

base units,
derived units,
supplementary units.

From the scientific point of view division of SI units into these three classes is to a certain extent arbitrary, because it is not essential to the physics of the subject.

Nevertheless the General Conference, considering the advantages of a single, practical, worldwide system for international relations, for teaching and for scientific work, decided to base the International System on a choice of seven well-defined units which by convention are regarded as dimensionally independent: the metre, the kilogram, the second, the ampere, the kelvin, the mole, and the candela (see II.1, page 3). These SI units are called *base units*.[1]

The second class of SI units contains *derived units*, i.e., units that can be formed by combining base units according to the algebraic relations linking the corresponding quantities. Several of these algebraic expressions in terms of base units can be replaced by special names and symbols which can themselves be used to form other derived units (see II.2, page 6).

Although it might be thought that SI units can only be base units or derived units, the 11th CGPM (1960) admitted a third class of SI units, called *supplementary units*, for which it declined to state whether they were base units or derived units (see II.3, page 11).

The SI units of these three classes form a coherent set in the sense normally attributed to the expression "coherent system of units".

The decimal multiples and sub-multiples of SI units formed by means of SI prefixes must be given their full name *multiples and sub-multiples of SI units* when it is desired to make a distinction between them and the coherent set of SI units.

[1] Translators' note. The spellings "metre" and "kilogram" are used in this US/UK translation in the hope of securing worldwide uniformity in the English spelling of the names of the units of the International System.

II. SI UNITS

II.1 Base units

1. *Definitions*

a) Unit of length.—The 11th CGPM (1960) replaced the definition of the metre based on the international prototype of platinum-iridium, in force since 1889 and amplified in 1927, by the following definition:

> *The metre is the length equal to 1 650 763.73 wavelengths in vacuum of the radiation corresponding to the transition between the levels $2p_{10}$ and $5d_5$ of the krypton-86 atom.* (11th CGPM (1960), Resolution 6).

The old international prototype of the metre which was legalized by the 1st CGPM in 1889 is still kept at the International Bureau of Weights and Measures under the conditions specified in 1889.

b) Unit of mass.—The 1st CGPM (1889) legalized the international prototype of the kilogram and declared: *this prototype shall henceforth be considered to be the unit of mass.*

With the object of removing the ambiguity which still occurred in the common use of the word "weight", the 3rd CGPM (1901) declared: *the kilogram is the unit of mass* [and not of weight or of force]; *it is equal to the mass of the international prototype of the kilogram.*

This international prototype made of platinum-iridium is kept at the BIPM under conditions specified by the 1st CGPM in 1889.

c) Unit of time.—Originally the unit of time, the second, was defined as the fraction 1/86 400 of the mean solar day. The exact definition of "mean solar day" was left to astronomers, but their measurements have shown that on account of irregularities in the rotation of the Earth the mean solar day does not guarantee the desired accuracy. In order to define the unit of time more precisely the 11th CGPM (1960) adopted a definition given by the International Astronomical Union which was based on the tropical year. Experimental work had however already shown that an atomic standard of time-interval, based on a transition between two energy levels of an atom or a molecule, could be realized and reproduced much more accurately. Considering that a very precise definition of the unit of time of the International System, the second, is indispensable for the needs of advanced metrology, the 13th CGPM (1967) decided to replace the definition of the second by the following:

> *The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom.* (13th CGPM (1967), Resolution 1).

[illegible]

d) Unit of electric current.—Electric units, called "international", for current and resistance, had been introduced by the International Electrical Congress held in Chicago in 1893, and the definitions of the "international" ampere and the "international" ohm were confirmed by the International Conference of London in 1908.

Although it was already obvious on the occasion of the 8th CGPM (1933) that there was a unanimous desire to replace those "international" units by so-called "absolute" units, the official decision to abolish them was only taken by the 9th CGPM (1948), which adopted for the unit of electric current, the ampere, the following definition:

The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross section, and placed 1 metre apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per metre of length. (CIPM (1946), Resolution 2 approved by the 9th CGPM, 1948)

The expression "MKS unit of force" which occurs in the original text has been replaced here by "newton" adopted by the 9th CGPM (1948, Resolution 7).

e) Unit of thermodynamic temperature.—The definition of the unit of thermodynamic temperature was given in substance by the 10th CGPM (1954, Resolution 3) which selected the triple point of water as fundamental fixed point and assigned to it the temperature 273.16 °K by definition. The 13th CGPM (1967, Resolution 3) adopted the name *kelvin* (symbol K) instead of "degree Kelvin" (symbol °K) and in its Resolution 4 defined the unit of thermodynamic temperature as follows:

The kelvin, unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water. (13th CGPM (1967), Resolution 4)

The 13th CGPM (1967, Resolution 3) also decided that the unit kelvin and its symbol K should be used to express an interval or a difference of temperature.

Note.—In addition to the thermodynamic temperature (symbol T), expressed in kelvins, use is also made of Celsius temperature (symbol t) defined by the equation

$$t = T - T_0$$

where $T_0 = 273.15$ K by definition. The Celsius temperature is in general expressed in degrees Celsius (symbol °C). The unit "degree Celsius" is thus equal to the unit "kelvin" and an interval or a difference of Celsius temperature may also be expressed in degrees Celsius.

f) Unit of amount of substance.—Since the discovery of the fundamental laws of chemistry, units of amount of substance called, for instance, "gram-atom" and "gram-molecule", have been used to specify amounts of chemical elements or compounds. These units had a direct connection with "atomic weights" and "molecular weights", which were in fact relative masses. "Atomic weights" were originally referred to the atomic weight of oxygen (by general agreement taken as 16). But whereas physicists separated isotopes in the mass spectrograph and attributed the value 16 to one of the isotopes of oxygen, chemists attributed that same value to the (slightly variable) mixture of isotopes 16, 17, and 18, which was for them the naturally occurring element oxygen. Finally an agreement between the International Union of Pure and Applied Physics (IUPAP) and the International Union of Pure and Applied Chemistry (IUPAC) brought this duality to an end in 1959/60. Physicists and chemists have ever since agreed to assign the value 12 to the isotope 12 of carbon. The unified scale thus obtained gives values of "relative atomic mass".

It remained to define the unit of amount of substance by fixing the corresponding mass of carbon 12; by international agreement, this mass has been fixed at 0.012 kg, and the unit of the quantity, "amount of substance",[2] has been given the name mole (symbol mol).

Following proposals of IUPAP, IUPAC, and ISO, the CIPM gave in 1967, and confirmed in 1969, the following definition of the mole, adopted by the 14th CGPM (1971, Resolution 3):

The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12.

Note. *When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.*

Note that this definition specifies at the same time the nature of the quantity whose unit is the mole.

g) *Unit of luminous intensity.*—The units of luminous intensity based on flame or incandescent filament standards in use in various countries were replaced in 1948 by the "new candle". This decision had been prepared by the International Commission on Illumination (CIE) and by the CIPM before 1937, and was promulgated by the CIPM at its meeting in 1946 in virtue of powers conferred on it in 1933 by the 8th CGPM. The 9th CGPM (1948) ratified the decision of the CIPM and gave a new international name, *candela* (symbol cd), to the unit of luminous intensity. The text of the definition of the candela, as amended in 1967, is as follows.

The candela is the luminous intensity, in the perpendicular direction, of a surface of 1/600 000 square metre of a blackbody at the tem-

[2] The name of this quantity, adopted by IUPAP, IUPAC, and ISO is in French "quantité de matière" and in English "amount of substance"; (the German and Russian translations are "Stoffmenge" and "количество вещества"). The French name recalls "quantitas materiae" by which in the past the quantity now called mass used to be known; we must forget this old meaning, for mass and amount of substance are entirely different quantities.

perature of freezing platinum under a pressure of 101 325 *newtons per square metre.* (13th CGPM (1967). Resolution 5).

2. Symbols

The base units of the International System are collected in table 1 with their names and their symbols (10th CGPM (1954), Resolution 6; 11th CGPM (1960), Resolution 12; 13th CGPM (1967), Resolution 3; 14th CGPM (1971), Resolution 3.

TABLE 1

SI base units

Quantity	Name	Symbol
length	metre	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature*	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

*Celsius temperature is in general expressed in degrees Celsius (symbol °C) (see Note, p. 4).

The general principle governing the writing of unit symbols had already been adopted by the 9th CGPM (1958), Resolution 7, according to which:

Roman [upright] *type, in general lower case, is used for symbols of units; if however the symbols are derived from proper names, capital roman type is used* [for the first letter]. *These symbols are not followed by a full stop* [period].

Unit symbols do not change in the plural.

II.2 Derived units

1. Expressions

Derived units are expressed algebraically in terms of base units by means of the mathematical symbols of multiplication and division. Several derived units have been given special names and symbols which may themselves be used to express other derived units in a simpler way than in terms of the base units.

Derived units may therfore be classified under three headings. Some of them are given in tables 2, 3, and 4.

TABLE 2

Examples of SI derived units expressed in terms of base units

Quantity	SI unit	
	Name	Symbol
area	square metre	m^2
volume	cubic metre	m^3
speed, velocity	metre per second	m/s
acceleration	metre per second squared	m/s^2
wave number	1 per metre	m^{-1}
density, mass density	kilogram per cubic metre	kg/m^3
concentration (of amount of substance)	mole per cubic metre	mol/m^3
activity (radioactive)	1 per second	s^{-1}
specific volume	cubic metre per kilogram	m^3/kg
luminance	candela per square metre	cd/m^2